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HIGHLY FOLDED BETWEEN NON-FOLDED STRATA AT TRENTON FALLS, N. Y.

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While engaged in field-work for the New York Geological Survey during the summer of 1907, excellent examples of highly folded between non-folded strata were observed at Trenton Falls, north of Utica, New York.[1] The phenomenon occurs in the classic Trenton limestone at its type locality. Vanuxem[2] and T. G. White[3] are the only ones who have described and attempted to explain the phenomenon at Trenton Falls.

Layers of highly folded and broken limestone included between perfectly straight and undisturbed limestone layers are well exhibited along the sides of the gorge at Trenton Falls. The impure limestone layers of both the folded and the non-folded portions average only a few inches in thickness and are separated by thin shale bands. The folded beds lie at two distinct horizons within the limestone formation which here shows a thickness of 270 feet. Prosser and Cummings[4] have made careful measurements of the thickness of the Trenton limestone at this locality. According to them the base of the lower folded zone lies 144 feet below the top of the Trenton. This contorted zone is about four or five feet thick and is visible only opposite the top of the lower part of High Fall and in the upper end of the gorge near Prospect village where the strata are highly inclined. It is well shown in Fig. A, Pl. III of White's article. Prosser and Cummings do not definitely refer to the upper folded zone in their paper, but its base occurs well down in their zone A^8 or about sixty-five to seventy feet below the top of the Trenton limestone. This contorted zone is about eight or ten feet thick and is well shown along the path opposite High Fall. From this point it may be traced along the sides of the gorge for nearly two miles to near the village of Prospect.

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[1] Published by permission of Dr. J. M. Clarke, State Geologist of New York.

[2] *Natural History of New York—Geology of the Third District*, p. 53.

[3] "The Faunas of the Upper Ordovician Strata at Trenton Falls, Oneida Co., N. Y.," *Transactions of the N. Y. Academy of Sciences*, Vol. XV, pp. 71–96.

[4] Prosser and Cummings, *Sections and Thickness of the Lower Silurian Formations on West Canada Creek and in the Mohawk Valley*, 15th Annual Report of the N. Y. State Geologist, pp. 615–27.

Within the folded zones the layers are, in rare instances, scarcely disturbed; sometimes they are only gently folded; most commonly they are highly twisted or contorted; while occasionally some of the layers are broken and pushed or faulted over others.

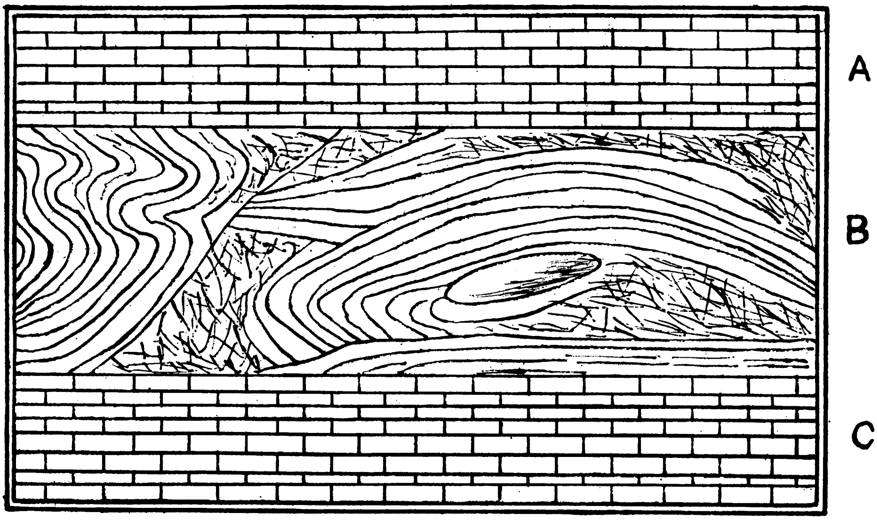

FIG. 1.—Sketch showing highly folded and broken limestone layers between undisturbed beds as seen along the foot-path opposite the top of High Fall, Trenton Falls, N. Y. Scale: one inch = six feet.

In those places where the folding has not been carried to an extreme, numerous observations show the axes of the folds to run generally from N. 50° E. to N. 65° E. The strike of these minor folds corresponds closely to the strike of a fault which the writer has found to extend from Prospect village past the village of Trenton. Also the whole Trenton limestone formation has, in this vicinity, been thrown into a number of very low folds which show about the same strike as above given.

It should be noted that these highly folded layers occur only in a very local district. Numerous observations are not possible because of the heavy drift covered areas, but, as far as can be ascertained, these highly folded layers are visible only in the Trenton Falls gorge and in the bed of Cincinnati creek, one and one-half miles southwest of Prospect. Along Mill creek, near Gravesville, several miles to the southeast, most of the Trenton section is exposed but the folded layers have not been found there.

Similar phenomena of highly folded between non-folded strata have been observed in the stratified clay banks of Pleistocene age along Black River to the north of Trenton Falls and also in the banks along the canal feeder west of Forestport. The latter occurrence has been described and figured by Vanuxem.[1]

CAUSE OF THE FOLDING[2]

Vanuxem[3] states that the folded layers are more thoroughly crystalline than the undisturbed layers above and below and that as the material of the disturbed layers was being crystallized it caused an expansion which manifested itself laterally by throwing the layers into folds. However, a careful examination of the layers in the folded zone and those above and below fails to show any real difference in degree of crystallization. Even if such a difference in degree of crystallization were present, it is difficult to see how simple crystallization of the mass could bring about such a considerable lateral expansion.

T. G. White[4] cites Professor W. O. Crosby as suggesting that the folds may have been caused by the great weight of overlying strata. According to this view it is extremely difficult to explain the sharp and even overturned folds and the minor thrust faults which imply a distinct shortening of the layers within the folded zones.

In many places the structure of the upper folded zone greatly simulates cross-bedding and the writer was at first of the opinion that it, in reality, did show cross-bedding. The close association, in the same zone, of truly folded and broken strata soon caused this idea to be cast aside. White[1] gives photographs showing supposed overlap structure and channel filling. These structures appear to be merely parts of the disturbed zones, described in this paper, where the beds have been broken or only gently folded.

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[1] *Op. cit.*, pp. 214, 215.

[2] The writer here wishes to express his thanks to Dr. C. K. Swartz of the Johns Hopkins University for suggestions regarding the cause of the folding.

[3] *Loc. cit.*, p. 90.

[4] *Op. cit.*, pp. 88–90.

It has occurred to the writer that the phenomenon might have been due to a lateral compression within the region, which caused most of the limestone beds to become denser without being greatly folded, while certain other layers yielded to the compressive force by folding. Such an explanation would imply a difference in texture between the folded and non-folded strata, but such a difference is not noticeable. Also it would seem to assume that the folded zone was more rigid while the evidence appears to indicate, if anything, that it was less rigid.

It is thought that the folded structure at Trenton Falls was in reality caused by a differential movement within the mass of the Trenton limestone. That the whole body of the limestone has been moved is clearly demonstrated by the existence of a thrust fault, of considerable throw, passing Prospect village. The displacement was sufficient to cause beds of the middle Trenton to slide over beds of the upper Trenton. Near the fault-plane the beds on the upthrow side are bent upward at angles of from thirty to forty degrees. The following figure, shows the relation of the fault to the folded zones.

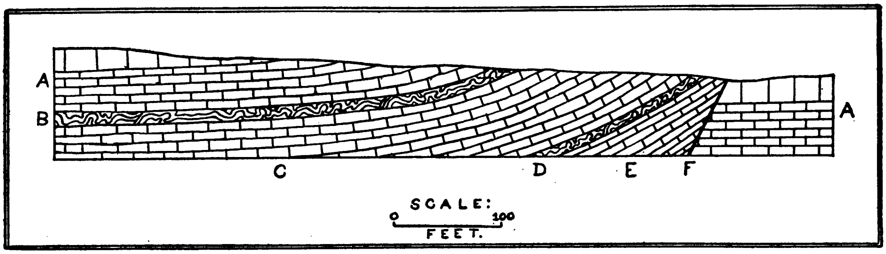

FIG. 2.—Section showing the position of the two folded zones in the Trenton limestone and their relation to the thrust fault at Prospect, near Trenton Falls, N. Y.

It is easy to see how when the force of compression was brought to bear in the region there would be a tendency for the upper Trenton beds on the upthrow side to move more easily and consequently faster than the lower Trenton beds. For instance the portion A in

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[1] *Op. cit.*, Pl. III, Fig. B, and Pl. IV, Fig. B.

Fig. 2 being separated from C by an intermediate mass B of slightly less rigidity would slide over C and cause the portion B to become ruffled or folded. Occasionally parts of zone B would become fractured or faulted. The portion B would need to be only slightly less rigid than the adjacent portions. The somewhat thinner limestone layers separated by thicker shale partings would be sufficient to cause the part B to be thus less rigid. A similar explanation would also apply to the lower folded zone. The folded zones thus merely indicate horizons of weakness along which the differential movement has taken place.

As thus explained it is evident why the strike of the minor folds, the strike of the fault, and the strike of the large low folds of the region should all be parallel, since all these phenomena were produced by the same pressure. Also the local character of the phenomena under discussion is readily explained, since the conditions for their formation exist only in the vicinity of the fault.

Where phenomena of this kind occur even in regions of low folds, but without faults, it is thought that the above explanation will suffice, because during the process of folding there would be more or less of a tendency for certain strata to slide over others. Where the conditions of relative rigidity, etc., were favorable, certain strata just beneath the sliding masses might become ruffled or folded.

The locally folded clay layers between non-folded layers along Black River, above mentioned, are to be explained in a somewhat similar manner. Vanuxem says: "The layers show a series of contortions of different kinds, for which no cause can reasonably be assigned but different degress of lateral pressure." Since there is no noticeable difference between the characters of the disturbed and the undisturbed beds and since the intensity of the folding is often so great, Vanuxem's explanation is not at all satisfactory. The required differences in degree of lateral pressure are altogether too great. The writer believes that, in principle, the explanation given for the Trenton Falls occurrences applies here also, although in the case of the clay beds the movement of the upper over the lower masses may have been caused by ice action or by having been pulled down the hillsides by gravity. Or as Salisbury and Atwood[1] have suggested for such a phenomenon in Pleistocene clay, the cause may have been lake ice or "the grounding of an iceberg on the surface before the overlying layers were deposited." In any case the cause of the movement in these superficial clays appears to be different from that of the ancient Trenton limestone.

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[1] *Jour. Geol.*, Vol. V, 1897, p. 143.